Electro-Optical System Simulation and Performance Prediction Extensions to EODES

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LONG-TERM GOALS

The EODES suite of electro-optical system models is designed to provide a high-fidelity simulation capability and accurate performance prediction tools. EODES simulations are being used to analyze the performance of existing electro-optical identification (EOID) systems and to inform new system design concepts. Performance prediction tools are being incorporated into tactical decision aids with near real-time performance assessments for available EOID assets to assist mine countermeasures (MCM) commanders and mission planners in formulating effective tactics. The long-term goal is to develop a complete set of validated models for underwater and airborne electro-optical systems and extend the simulation and performance prediction capabilities to all relevant Navy systems.

OBJECTIVES

EODES electro-optical sensor models are based on high-fidelity physical models of radiative transfer in turbid media under the assumption of small-angle scattering and Fourier optics models for various scanning systems [1]. A key objective of this program is to develop flexible and efficient numerical solution techniques for these physical models to provide high-fidelity, computationally efficient simulation and performance analysis. The physical and systems models already incorporated within EODES have undergone a rigorous validation process [7,8] and continuous validation remains a key objective. The aim is to provide modeling and simulation capabilities that are relevant to the Navy, whether in the engineering design phase of next-generation EOID systems or for tactical performance prediction. System models, as they are developed, will be submitted to the Oceanographic and Atmospheric Master Library (OAML) Software Review Board (SRB) for certification as Navy standard models. Performance prediction models are expected to be transitioned to Naval Oceanographic Office (NAVOCEANO) upon receiving OAML certification.

APPROACH

EODES implements high-fidelity physical and mathematical models for radiative transfer and image scanning. Simulation and performance prediction tools address a wide variety of electro-optical sensor

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types, provide for detailed specification of the system design and environmental conditions, and have been rigorously validated against field test and laboratory data. EODES software is computationally efficient, very accurate, and portable across various computer platforms. EODES products are used to analyze engineering design tradeoffs, inform investment and procurement decisions, and to provide tactically relevant system performance estimates.

WORK COMPLETED

Metron provided analysis of a co-located, pulsed scanning system that is currently under development. This electro-optical identification (EOID) system is expected to provide more robust performance and operate at longer ranges. The system is being designed and developed by teams from Scripps Institution of Oceanography (POC: Jules Jaffe) and Lockheed Martin Aculight Corporation (POC: Dan Templeman). A key design goal is to fit the sensor into a small form factor unmanned underwater vehicle (UUV). Metron has developed models and performed analysis to examine design tradeoffs for various optical configurations and hardware options. Metron evaluated the impact of receiver aperture area, laser power, and pulse-to-pulse energy instability on the signal-to-noise ratio (SNR) at various standoff distances in turbid water.

Metron also carried out an analysis of LIDAR performance as a function of the laser source distribution, the receiver instantaneous field of view, and the water turbidity for various system configurations. The objective was to relate these variables to the system attenuation coefficient (K_{sys}) of the LIDAR equation, which is the exponential decay rate of the LIDAR signal with range (or, equivalently, time). The analysis is key to understanding the performance of pulsed (ranging) sensors such as those incorporated in the new Scripps/Aculight system, the RAMICS system, and the AQS-20 and ALMDS systems, both of which use a Streak Tube Imaging Lidar (STIL) sensor.

The EODES performance prediction model for the AQS-24 electro-optical identification (EOID) system was submitted to the Oceanographic and Atmospheric Master Library (OAML) Software Review Board (SRB) for certification as a Navy standard model. This review process continued through FY09, and a final report is expected at the October meeting of the SRB. The review process required a continuous interaction with the CNMOC Independent Model Review Panel (CIMPREP) to clarify technical points, answer questions, and provide additional supporting data. A reworking of the model documentation to include security markings was also performed.

RESULTS

To accommodate deployment concerns, a programmatic decision was made to field the next-generation underwater imaging system aboard a 9” UUV, a substantially smaller platform than originally envisioned. The reduction in platform size imposed limitations on certain subsystem configurations. A significant reduction in the area of the receiver aperture was required for the system to fit into the smaller UUV. This reduction had a negative impact on the estimated signal-to-noise ratio (SNR) that would potentially affect the ability of the system to meet critical performance requirements. Moving to a smaller UUV forced a close examination of major engineering design decisions and precipitated an extensive trade-off analysis to identify ways to compensate for the SNR reduction and to restore the ability of the system to meet its original performance specifications.

The analysis identified several design alternatives. One way to increase the SNR is to increase the pulse energy. A second alternative is to optimize the instantaneous field of view (IFOV) of the receiver. A third alternative is to employ multiple receivers to compensate for the reduction in aperture area. A careful study revealed that modest changes to the IFOV of a single receiver could yield significant improvements to the SNR by excluding extraneous light reflected from the bottom scene. The original design also called for the co-location of the source and receiver. Analysis showed that a slight separation of the source and receiver would leave the system nearly co-located, and that the effects of parallax could be mitigated through other design changes. Finally, a study was performed to investigate the trade-off between beam divergence and laser spot size. It was found that SNR increased when the beam divergence decreased, but at the cost of increasing the spot size. However, the increase in spot size could be accommodated while satifying the system resolution requirement.

Further analysis focused on the effect of pulse-to-pulse energy instability on the signal-to-noise ratio (SNR) and system image quality. It was established that pulse energy instability would be manifest in the imagery as uncorrelated noise. Synthetic system images were generated to study image quality degradation due to pulse energy instability. The study related the degradation to loss of contrast and diminished resolution at fine levels of detail. Furthermore, the analysis showed that pulse energy instability imposes a ceiling on the SNR in inverse proportion to the variance of the instability. For the amount of instability expected for the current system design, the SNR ceiling is estimated to be high enough to allow the system to meet its performance specifications.

A separate analysis has shown that the exponential attenuation rate of airborne LIDAR signals is dependent on the optical configuration of the system and water turbidity. Theoretical analysis and numerical simulation found that the system attenuation coefficient is bounded from below by the diffuse attenuation coefficient (K_d) and from above by the beam attenuation coefficient (c). In particular, LIDAR signals from airborne systems that employ broad laser illumination, an open receiver aperture, or both were found to have an exponential decay rate close to K_d. Airborne LIDAR systems that employ an extremely narrow laser beam and extremely narrow field of view had an exponential decay rate approaching c. Other airborne systems had decay rates in between these limiting values (see Figure 1). Monostatic underwater systems behaved similarly, and the decay behavior of bistatic underwater systems was more complicated due to the complex radiative transfer problem near the sensor. EODES models were used to estimate the exponential decay rates for different airborne LIDAR systems to establish their maximum depth penetration in waters of different turbidities.

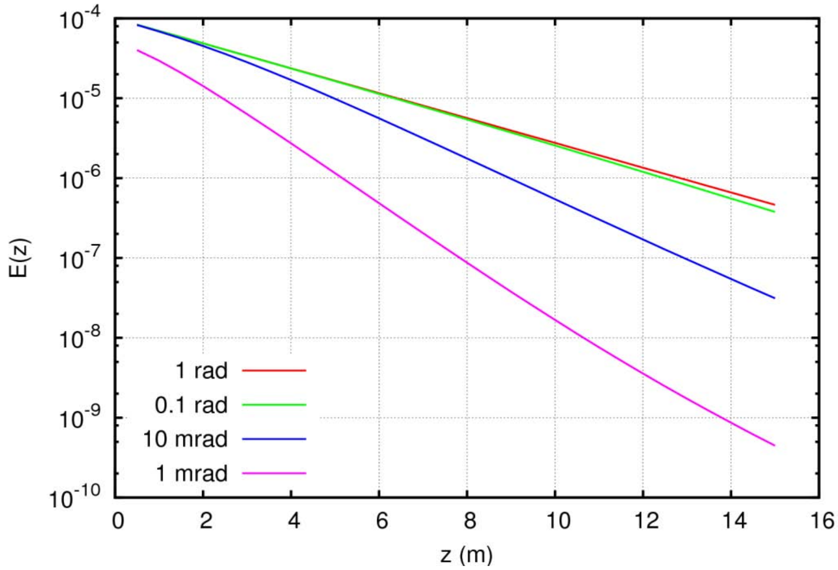

Figure 1: Normalized irradiance at the receiver as a function of depth for a narrow beam laser source and several receiver aperture half-angles, where the exponential decay rate is seen to be greater for smaller aperture angles (plot is on a log-linear scale).

The OAML certification process is nearing completion, with a final report from the CIMREP tentatively scheduled to be presented at the October meeting of the OAML SRB. If certified, EODES performance prediction models will be the first electro-optical models to be included in the OAML.

IMPACT/APPLICATIONS

EODES simulation and performance prediction software was developed for the purpose of analyzing existing and prospective electro-optical systems and to provide electro-optical mine identification (EOID) system performance estimates to inform tactical decisions for mine countermeasures (MCM). EODES models are currently being used to examine the performance of several underwater systems for the Office of Naval Research (ONR) and airborne lidar systems for the Naval Sea Systems Command (NAVSEA).

TRANSITIONS

EODES performance prediction software is expected to transition to the Naval Oceanographic Office (NAVOCEANO). EODES models are also being used to evaluate performance of airborne LIDAR systems for the Naval Sea Systems Command (NAVSEA).

RELATED PROJECTS

This project is a continuation of a previous effort to develop “A Comprehensive Model for Performance Prediction of Electro-Optical Systems” (ONR contract number N00014-06-C-0070). Another related project was concerned with the demonstration of EODES performance prediction capabilities at the RIMPAC-08 Navy exercise and the submission of EODES software for possible inclusion in the Oceanographic and Atmospheric Master Library (ONR contract number N00014-08-M-0007).

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